



Title: AOS Standard Operating Procedure: BAT – Post-Processing of Bathymetric and Side Scan Sonar Data from NEON Lakes and Non-Wadeable Streams		Date: 06/22/2023
NEON Doc. #: NEON.DOC.004856	Author: B. Jensen	Revision: D

AOS STANDARD OPERATING PROCEDURE: BAT – POST-PROCESSING OF BATHYMETRIC AND SIDE SCAN SONAR DATA FROM NEON LAKES AND NON-WADEABLE STREAMS

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	01/03/2020	ECO-06325	Initial release
B	01/24/2022	ECO-06753	<ul style="list-style-type: none">Updating all processing steps associated with the switch from Hummingbird to BioSonics MX sonar equipment
C	03/22/2022	ECO-06793	Minor formatting update
D	06/22/2023	ECO-06801	<ul style="list-style-type: none">Updated shoreline polygon creation at sites where the shoreline cannot be walked - SOP C.2Added Plant shapefile and csv to the table of L4 outputsMigrated to template Rev ESOPs renamed from SOP 1 to SOP A and so on to match current template



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1 DESCRIPTION

Contained in this document are details concerning the standard operating procedure (SOP) for collecting, processing, and producing Level 4 bathymetric and habitat maps at NEON aquatic lake and non-wadeable river sites. Specifically, the processes necessary to convert “raw” electronic survey data and field measurements into Level 4 spatial data products and their associated uncertainties are described. These data are collected using a boat-mounted system applied during manned surveys of NEON lakes and river sites. A Biosonics MX, single beam, down looking echo sounder and GPS are used to collect backscatter (signal strength) data. Sonar timeseries are converted into depth contour lines for the development of a bathymetric map (**Figure 1a**) and a habitat map (**Figure 1b**). Data is collected using the Visual Acquisition software and processed using the Visual Aquatic software, which are both freely available from the www.biosonicsinc.com website. Bathymetric surveys are completed at least every 5 years; if an extreme event results in substantial changes to the physical environment then an out-of-cycle survey may be requested.

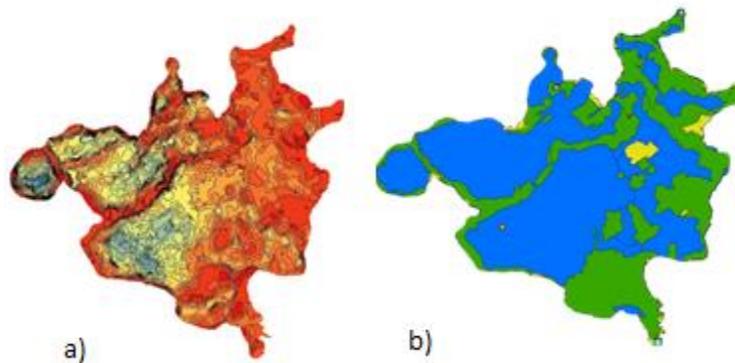


Figure 1. Example bathymetric map (a) and a classified habitat map (b).

1.1 Purpose

This document details how to create NEON Level 4 data products for bathymetric and habitat maps from Level 0 data, and how to organize ancillary data obtained via instrumental measurements using steps outlined in the AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]). It includes a description of the field data collection procedures, appropriate background information, an itemized list of data products, quality assurance and control methods used, and approximations and/or assumptions made for the collection of data used to create the bathymetric and habitat maps.

1.2 Scope

This document provides a change-controlled version of an Observatory procedure. Documentation of content changes (i.e. changes in particular tasks or safety practices) will occur via this change-controlled document, not through field manuals or training materials.



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1.3 Applies To

This document describes how to derive Level 4 data from Level 0 data for the AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]). It does not provide computational implementation details, except for cases where these stem directly from SOP choices and assumptions explained here.

1.4 Acknowledgments

N/A



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2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain higher-level information that is implemented in the current document. Examples include designs, plans, or standards.

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.005003	NEON Scientific Data Products Catalog
AD[03]	NEON.DOC.002652	NEON Data Products Catalog
AD[04]	NEON.DOC.004104	NEON Science Data Quality Plan
AD[05]	NEON.DOC.005001	NEON Coordinate Systems Specification
AD[06]	NEON.DOC.050005	Field Operations Job Instruction Training Plan

¹ Note that CI obtains calibration and sensor values directly from an XML file maintained and updated by CVAL in real time. This report is updated approximately quarterly, so there may be a lag time between the XML and report updates.

2.2 Reference Documents

Reference documents contain information that supports or complements the current document. Examples include related protocols, datasheets, or general-information references.

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Data Products Catalog
RD[04]	NEON.DOC.001197	AOS Protocol and Procedure: BAT – Bathymetry and Morphology of Lakes and Non-Wadeable Streams
RD[05]	NEON.DOC.003104	Datasheets for AOS Protocol and Procedure: Bathymetry and Morphology of Lakes and Non-Wadeable Streams
RD[06]	NEON.DOC.004857	NEON Standard Operating Procedure: Post-processing of Wadeable Stream Morphology Data from NEON Wadeable Streams
RD[07]	NEON.DOC.005221	AOS/TOS Standard Operating Procedure: Trimble GeoXH Receivers Setup and Use
RD[08]	DP4.00132.001	NEON User Guide to Bathymetric and Morphological Maps

2.3 External References

ED[01]	Heyman, W.D., J-L. B. Ecochard, and F.B. Biasi. 2007. Low-cost bathymetric mapping for tropical marine conservation – A focus on reef fish spawning aggregation sites. <i>Marine Geology</i> , 30: 37-50
ED[02]	Visual Aquatic User Guide: Post-Processing and Data Visualization Software for BioSonics Echosounder Systems: V1.0. BioSonics, Inc. Seattle, WA.

2.4 Acronyms

Acronym	Definition
DGPS	Differential Global Positioning System



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DP	Data Product
EBK	Empirical Bayesian Kriging
L4	Level 4
GCS	Geographic Coordinate System
GIS	Geographic Information System
GPS	Global Positioning System
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
PCS	Projected Coordinate System
SOP	Standard Operating Procedure
UTM	Universal Transverse Mercator
VA	Visual Aquatic
WAAS	Wide Area Augmentation System
WGS	World Geodetic System

2.5 Definitions

N/A

2.6 Spatial File Types and Extensions

2.6.1 Shapefile

Extension	Explanation
.shp	The main file that stores the geometry of a feature as a series of vertices (e.g. point, line, polygon)
.shx	The index file that stores the position of the feature geometry
.dbf	The dBASE table file stores the attribute information of the features and maintains a one-to-one relationship between geometry and attributes based on record number
.prj	The projections definition file stores geographic coordinate and projection system information
.xml	Extensible Markup Language file contains metadata associated with the file and can be viewed in a text editor
.sbn	Spatial index file for optimizing spatial queries (when used in conjunction with .sbx)
.sbx	Spatial index file for optimizing loading time of spatial queries (when used in conjunction with .sbn)
.cpg	Encoded plain text file describes shapefile text character set

2.6.2 Image File

Extension	Explanation
.tif	Tagged Image File format stores an array of pixels to form a high-quality raster graphic
.tfw	World File for TIF contains the location, scale, and rotation of the data that is stored as a .tif image for geographic reference



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2.6.3 Earth Viewer File

Extension	Explanation
.kml(z)	Keyhole Markup Language file is an xml format extension for visualizing geographic data in an internet-based geobrowser like Google Earth

2.6.4 Sonar File

Extension	Explanation
.dt4	File format used for processing data by Visual Acquisition
.rtpx	File format used when collecting data with the Biosonics MX unit, can be converted to .dt4 using the utilities in Visual Acquisition

2.6.5 Trimble GPS File

Extension	Explanation
.ssf	Data file used by Trimble GIS mapping software applications to log GPS data



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3 PERSONNEL

3.1 Training Requirements

All technicians must complete protocol-specific training as required in the Field Operations Job Instruction Training Plan (AD[06]). Additional protocol-specific required skills and safety training are described here.

3.2 Specialized Skills

Use BioSonics and arcMap or arcPro software to process field data.



4 DATA PRODUCT DESCRIPTION

4.1 Variables Reported

The Bathymetry and Morphology of Lakes and Non-Wadeable Streams (RD[04]) and related L4 DPs provided by the procedures documented in this SOP are displayed in the accompanying file NEON Data Variables for Bathymetric and Morphological Maps (NEON.DP4.00132). A summary of the L4 DPs associated with this SOP are detailed in the following table.

Table 1. Metadata for L4 Data Products Associated with the Bathymetric (BATH) and Habitat (HAB) Map with Estimated File Sizes and Descriptions.

File Type	File Size Range	Description
BATH_contour.shp	70 kb – 300 kb	Shapefile format containing vector data of contour depth lines at a specific interval.
BATH_shorePolygon.shp and BATH_shoreline.shp	100 kb	Line and polygon shapefile format containing vector data of the closed boundary around the shoreline.
BATH_tracks.csv	500 – 1,000 mb	Table containing the spatial data for each sonar ping group (longitude, latitude, depth, time) as well as the raw exports from the bottom elevation, plant height, plant coverage, and bottom type analyses.
BATH_volume.csv	< 1,000 kb	Table containing water volume calculation, 2D area (flat surface), and 3D area (sum of surface area) calculations at successive depths.
BATH_GE.kmz	300 kb – 2,700 kb	Earth Viewer file of derived bathymetric map viewable in Google Earth.
BATH_Map.pdf	400 kb – 1,300 kb	Portable document format for viewing derived bathymetric map.
BATH.tif	1,000-1,700 kb	Image file of interpolated depths.
HABITAT.shp	40 - 300 kb	Shapefile format of classified habitat features derived as polygons.
HABITAT_area.csv	< 500 kb	Table containing unique fields for each habitat classification and total area of each classification
PLANT.shp	40 - 300 kb	Shapefile format of the binned plant coverage features derived as polygons.
PLANT_area.csv	< 500 kb	Table containing unique fields for each plant cover bin and total area of each classification
HABITAT_GE.kmz	150 - 170 kb	Earth Viewer file of derived habitat map viewable in Google Earth.
HABITAT_Map.pdf	156 – 350 kb	Portable document format for viewing derived habitat map.
VAdataset.vhmcfg and VAdataset_AnalysisResults Folder	100-200 kb	Processed sonar data and the necessary accessory files to open the .vhmcfg file in Visual Aquatics



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4.2 Input Dependencies

Input dependencies provided in **Table 2**.

Table 2. List of the equipment used to collect L0 DPs that are transformed into L4 DPs in this SOP.

Description	Sample Frequency	Units	Data Product Number
Biosonics MX Habitat Echosounder		1	
Trimble GPS GEO XH 6000 or 7000	1 Hz; decimeter (10 cm/4 inch) accuracy positioning	1	DP1.20086.001

4.3 Product Instances

The equipment will be deployed to collect input variables at NEON lake and river sites. Bathymetry data will be collected every 5 years (at minimum) during the second biological sampling bout and during the period of peak greenness. Peak greenness is defined as the range of dates where MODIS EVI is within 90% of the site maximum. Lake sites include:

- Domain 03 - SUGG and BARC
- Domain 05 - CRAM and LIRO
- Domain 09 - PRLA and PRPO
- Domain 18 - TOOK

Non-wadeable (river) sites include:

- Domain 03 - FLNT
- Domain 08 - BLWA and TOMB

4.4 Temporal Resolution and Extent

The finest temporal resolution at which bathymetric and morphological data are reported is the endDate, a single date on which survey data were collected. Bathymetric and morphological surveys are conducted at each lake and river site at least once every five years. Should an extreme event result in significant changes in water level, morphology, or habitat, an additional survey may be conducted sooner than every 5 years once safe conditions allow.



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5 SCIENTIFIC CONTEXT

Bathymetry and morphology are key parameters for defining the hydrological, physical, chemical, and biological characteristics of lakes and non-wadeable streams. Water level, volume, area, and stage curve relationships provide spatial quantitative information. They also impart a governing role on hydrodynamics, water quality, biogeochemical relationships, and biological productivity.



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6 STANDARD OPERATING PROCEDURES

SOP A Post Processing the Raw L0 Data

A.1 Post Processing in Visual Aquatic

The Visual Aquatic User Guide (ER[02]) should be followed during all analyses. This document provides high level steps, NEON specific workflows, and additional notes. The different analysis types should be performed in the SOP order below.

A.2 Required Platforms and Tools

1. BioSonics Visual Aquatic 1.0 – free software
2. BioSonics Visual Acquisition 6.4.1 – free software

A.3 Creating or Opening a Dataset

1. For new projects:
 - a. Open Visual Aquatic> File>New Dataset
 - b. Navigate to the workspace folder where the .dt4 and .rptx files are saved.
 - i. Note: Running all BioSonics processing from a local drive results in faster processing times.
 - c. Name and save the dataset.
 - d. In VA open File>Add files to load all the .dt4 files from the survey.
2. For existing projects:
 - a. In Visual Aquatic go File>Load Dataset



Figure 2. Key features in the Visual Aquatic tool bar.



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A.4 Bottom Detection Analysis

1. Select all the records and click the Play button. In the pop up check the “Bottom Detection” box and click start.
2. Each record will need to be manually checked. For each record:
 - a. Highlight the row and click the “playback” button (symbol with red line and blue dots).
 - b. From the drop down menu choose “bottom detection”.
 - i. The brown line is the initial result from the analysis.
 - c. Smooth and correct the brown line as needed. Pings are averaged by 10 in the export phase so the goal is not complete accuracy but to remove any erroneous peaks or valleys that would greatly affect an average.

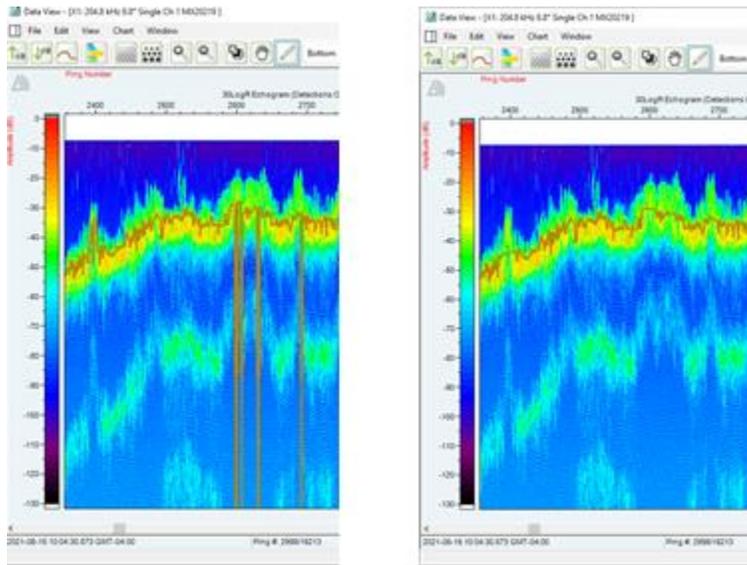


Figure 3. Before and after manually editing the bottom depth results (brown line).

- i. Take a screenshot and made note of any instances where the sonar data looks strange and a targeted ground truth point is needed. Record the latitude and longitude from the bottom right of the screen.



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- d. If the bottom line should be less than .5m, manually draw the bottom line following the curve (for example, interpolating where the top of the green shading would be). Make a separate note of how deep the water is at those pings. Once the data is fully processed and exported filter where elevation depth equals 0.5 (output leaves no decimal places if above 0.5 compared to all the other pings) and manually update the depth with the values from your notes.

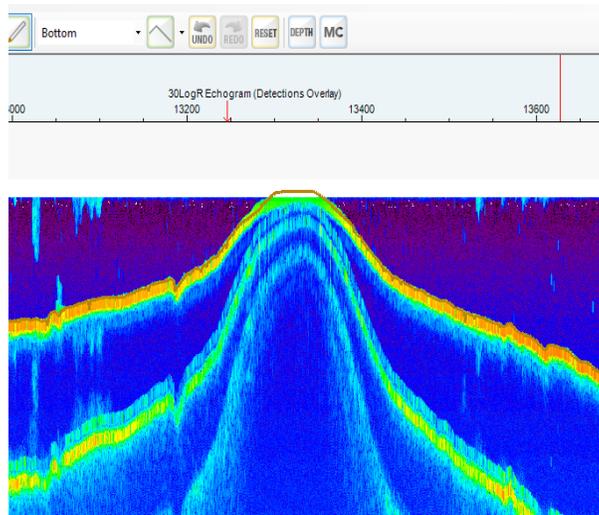


Figure 4. After manual edits to the bottom depth results to account for a shallow section less than 0.5m.

- e. Once the edits are complete close the file and the changes will be saved. The record will now say “Manual Edit” under the “Bottom Depth” header if any edits were necessary.
2. Complete manual checks and edits for all the records in the dataset.

A.5 Plant Coverage Analysis

1. Select all the records and click the “Configure Analysis” button.
 - a. Click on the “Plant Detection” tab and change the “Maximum Plant Depth” to the site-specific plant colonizable depth as captured in the NEON User Guide to Bathymetric and Morphological Maps (RD[08]) appendix tables and click “ok”.
2. Click the “Play” button. In the pop up check the “Plant Detection” box and click start.
3. Each record will need to be manually checked.
 - a. For each record highlight the row and click the “playback” button (symbol with red line and blue dots).
 - b. From the drop-down menu choose “Plant Detection”.
 - i. The green line is the initial result from the software.



- ii. Plants appear on the echogram with a visible “beard” of noise under the bottom depth line

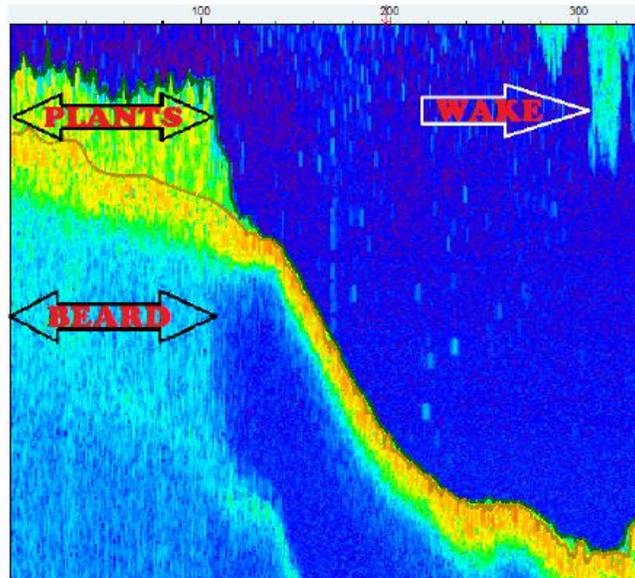


Figure 5. Examples of plants, the “beard”, and microbubbles from a wake in the echogram. Taken from ER[2].

- c. Smooth and correct as needed. Pings are averaged out by 10 in the export phase so the goal is not complete accuracy but to remove any erroneous peaks or valleys that would greatly affect an average.
 - d. Take a screenshot and made note of any instances where the sonar data looks strange and a targeted ground truth point is need. Record the latitude and longitude available on the bottom right of the screen.
 - e. Once the edits are complete close the file and the changes will be saved. The record will now say “Manual Edit” under the “Plant” header if any edits were necessary.
4. Complete manual checks and edits for all the records in the dataset.

A.6 Bottom Type Analysis

1. Select all the records and click the “Configure Analysis” button.
 - a. Click on the “Bottom Type” tab and change the “Number of clusters” to the number of unique bottom types identified by Field Science in the random ground truth points (see the associated Fulcrum data).
2. Click the “Play” button. In the pop up check the “Feature Extraction” and “Bottom Type” boxes and click start.
3. Follow the gridding analysis steps below to grid and export the map.



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4. Re-run with plus and minus 1 cluster from the original run.
 - a. Open the “Run Analysis” and click “view/change bottom type clusters...” for faster analysis.
 - b. Note: the previous analysis is overrun each time so be sure to export before re-running the bottom type analysis with a new number of clusters.

A.7 Gridding Analysis

The gridding analysis is used to for both plant coverage and bottom type.

1. Select all the records and go View>Show Map View.
2. Change the coordinate system.
 - a. Map View> Base Map Properties
 - b. Choose WGS84 and the UTM projection for the site.
 - i. Tip- if nothing shows up on the map first check that the “data points” under “layer opacity” is greater than 0%.
3. In map view zoom in and measure the distance between 3 random data points. Record the smallest.
4. Under “Grid Tool” select “Gridding/Contouring”.
 - a. Check either “Plant Height, Coverage” or “Bottom Type” under “Create Grids”.
 - b. Start with a grid cell size of “1”. For larger sites this may need to be increased if the export becomes too large to load or manipulate in ArcMap.
5. Choose “Kriging” from the drop down and hit the “...” to change the settings.
6. Follow the instructions for the kriging gridding in the VA user guide (ER[2]). Below are the variables that should be adjusted for each run.
 - a. Distance Bin Size:
 - i. Enter the point distance that was recorded in step 3.
 - ii. Hit “Compute” and look at the “Error” in the Model Box.
 1. Keep increasing by 1 and re-computing until the best variogram fit and lowest error is determined.
 2. Following the VA user guide example, “4” is typically used.
 - b. Variogram modeling:
 - i. Highlight each row and click the automatic optimization for “type, range, nugget, sill”.



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- ii. All variogram memberships should use the same type, manually change if one is different.
7. Click “OK” and then “Start”.
 8. Once the gridding is complete check the map view to see the output.
 - a. Under Map>Configure choose the correct “Map View Data Type” from the drop down.
 - b. Change the number of colors to match the number of clusters for the bottom type output or the number of plant coverage bins you want to see in the output.
 9. View the map. Change the “Gridded Data” to 100% in the “Layer Opacity” screen.
 10. For bottom type grids:
 - a. If the map contains unique clusters and not just a few scattered pixels then export the map. If unsure, err on exporting the map. See the example in the figure below.

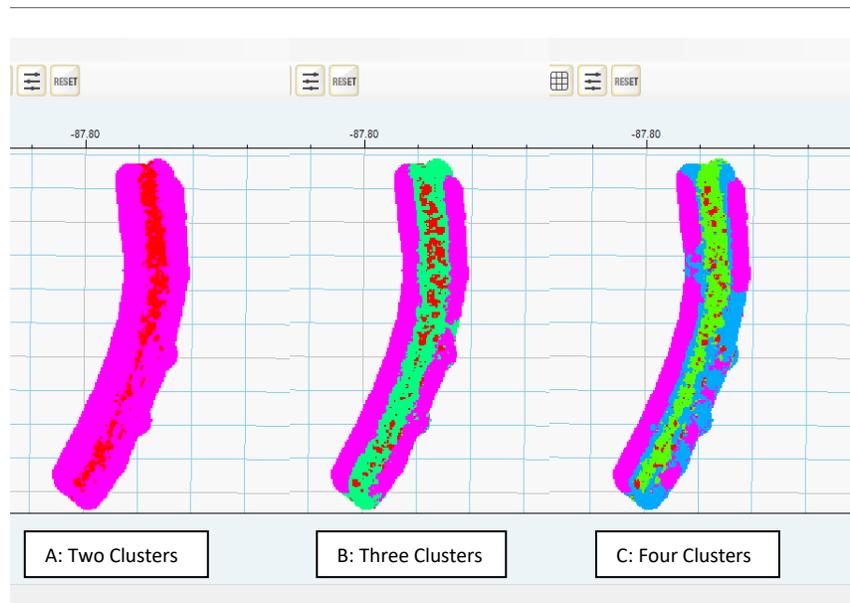


Figure 6. Map of three different outputs for gridded bottom types. In map A the polygons are well defined, and this result should be exported. Map B has some pixilation occurring, but since 3 clusters matches the number of unique bottom types in the random ground truth points this map should be exported as well. In Map C, the fourth bottom type, in red, does not have well defined polygons and the map should not be exported.

A.8 Exporting Files

Note: For all file names “surveyDate” should be the last date sonar data was collected in YYYYMMDD format.

1. To export the bottom depth results and create the tracks.csv:



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- a. Check parameters:
 - i. Under “View” go to “Map View”.
 - ii. Go Map>Configure
 1. Report interval should be 10 pings.
 2. Under “Plant Depth” plant “Height Threshold” should be 0.05m.
 - b. On the main screen click the export symbol (letter with the arrow).
 - c. Click all the boxes under the “CSV Export” window and change the filename to: “DXX_SITE_BATH_surveyDate_tracks.csv”.
 - d. Click “Start”.
 - e. The .csv will be exported to the VA analysis folder.
2. To export the gridded maps:
- a. In Map View >Grid Tools> Export
 - b. Click the map type and then shapefile and grid cells.
 - c. Include the number of clusters used in the output file name.
 - d. The shapefiles will be exported to the VA analysis folder.
3. To export marked events:
- a. Open Visual Acquisition.
 - b. Go to Utilities<File Utilities
 - i. Input File Type is “RTPX”.
 - ii. Choose Export Data to CSV Files and click the “...”.
 - iii. Select “Mark Event” and make sure the Lat/Long/ and Comment fields are checked.
 - iv. Click Ok.
 - v. Click Process Files and browse to the rtpx files that contain marked events.
 - vi. Select all and hit “open”.
 - c. Run the code below in R to combine all the outputs into a single .csv.

```
folder <- " # path to folder that holds multiple marked event .csv files
file_list <- list.files(path=folder, pattern="*.csv") #only add files with .csv ending
#merge all into one dataframe
data <-
```



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```
do.call("rbind",  
  lapply(file_list,  
    function(x)  
      read.csv(paste(folder, x, sep=""),  
        stringsAsFactors = FALSE)))  
write.csv(data, paste(folder, 'combinedMarkedEvents.csv', sep=""),row.names = F)
```



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SOP B Post Processing in GPS Pathfinder Office

All the .ssf files in L0 data folder will need to be postprocessed in GPS Pathfinder Office and exported to a shapefile format.

B.1 Required Platforms and Tools

1. Trimble GPS Pathfinder Office version 5.85

B.2 Differential Correction

1. Open GPS Pathfinder Office.
2. Follow SOP B.1 in NEON.DOC.005221 (RD[07]) to set up the project and data view windows.
3. Follow SOP G.1 – G.2 in NEON.DOC.005221 (RD[07]) to post process each .ssf file. All files can be post processed at the same time.

B.3 Exporting

1. Follow SOP G.3 in NEON.DOC.005221 (RD[07]) to export the post processed data.
2. In step 5 select “Sample ESRI ShapefileSetup”.
 - a. Be sure to export in the correct UTM zone and WGS 84 datum.



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SOP C Post Processing in ArcMap

The rest of the analysis and map creation steps take place in ArcMap. The instructions below are written for ArcGIS version 10.5 but the same overarching workflow could be used in different versions or different software.

Bathymetry outputs (contours, volume amounts per elevation) are created first, followed by a plant coverage shapefile, and bottom type shapefiles for each cluster exported from Visual Aquatics. Random ground truth points collected during the sonar survey are overlaid on top of the habitat layers.

Up to ten targeted ground truth locations are created for field teams to visit at the site and record bottom type and plant presence in areas where clarification is needed.

After the targeted ground truth points have been checked in the field, the sonar outputs, ground truth point data, and site knowledge are used to determine which bottom type model best fits the site and the final L4 files are created.

C.1 Required Platforms and Tools

1. ArcGIS - Version 10.5+ with extensions:
 - 1.1. Geostatistical Analyst
 - 1.2. Spatial Analyst
 - 1.3. 3D Analyst
2. ET Geo Wizards for ArcGIS 10.4+
3. Google Earth

C.2 Bathymetry

At sites where the shoreline data is collected with a GPS receiver while walking the perimeter:

The steps below describe how to merge the GPS data from the shoreline .ssf file with the bottom detection analysis from Visual Aquatic to create the bathymetric outputs.

1. Load the shoreline shapefile created in SOP B.3.
 - a. If needed, set the projection the correct UTM zone, WGS 84.
 - i. ArcToolbox>Data Management Tools>Projections and Transformations>Define projection.
 - b. Update the attribute table so the only columns are:
 - i. “Name”: text field, full site name



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4. Load the “DXX_SITE_BATH_surveyDate_tracks.csv” created in 5.1.7 into ArcMap.
 - a. File> Add Data
5. Display the xyz locations.
 - a. File > Add Data > Add XY Data
 - i. X Field: Longitude
 - ii. Y Field: Latitude
 - iii. Z Field: ElevationBottom
 - iv. Coordinate System of Input Coordinates > Edit > XY Coordinate System Tab > Geographic Coordinate Systems > World > WGS 1984 > OK > OK > OK
 - b. Note: if there are any manual edits to make to the bottom elevation values from step 3 in section 5.1.3 now is the time to do so using the “field calculator”.
6. Export the .csv Events file to shapefile.
 - a. Right click the Events layer created in step above Data > Export Data
 - i. Export: All features
 - ii. Use the same coordinate system as: shoreline polygon (UTM zone XXN, WGS 84)
 - iii. Output feature class: tracks
 - iv. Save as type: Shapefile



Figure 7. Map showing the track points from the sonar survey (maroon points) and the shoreline points (teal points) from the GPS file.



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At sites where the shoreline cannot be walked:

7. Load the “DXX_SITE_BATH_surveyDate_tracks.csv” created in 5.1.7 into ArcMap.
 - a. File> Add Data
8. Display the xyz locations.
 - a. File > Add Data > Add XY Data
 - i. X Field: Longitude
 - ii. Y Field: Latitude
 - iii. Z Field: ElevationBottom
 - iv. Coordinate System of Input Coordinates > Edit > XY Coordinate System Tab > Geographic Coordinate Systems > World > WGS 1984 > OK > OK > OK
 - b. Note: if there are any manual edits to make to the bottom elevation values from step 3 in section 5.1.3 now is the time to do so using the “field calculator”.
9. Export the .csv Events file to shapefile in the Workspace folder.
 - a. Right click the Events layer created in step above Data > Export Data
 - i. Export: All features
 - ii. Use the same coordinate system as: shoreline polygon (UTM zone XXN, WGS 84)
 - iii. Output feature class: tracks
 - iv. Save as type: Shapefile
10. Create a buffer around all the BioSonics track points:
 - a. ArcToolbox > Analysis Tools > Proximity > Buffer
 - i. Input Features: tracks
 - ii. Output Feature: tracksBuffer
 - iii. Distance: Unless Field Science indicates the average distance to the shore use 3m
 - iv. Dissolve Type: All
11. Combine all the buffer polygons into one polygon:
 - a. ArcToolbox > Analysis Tools > Overlay > Union
 - i. Input Features: tracksBuffer
 - ii. Output Feature: tracksBufferUnion
 - iii. Uncheck the “Gaps Allowed” box



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12. Dissolve the new polygons into one

- a. ArcToolbox > Data Management Tools >Generalization >Dissolve
 - i. Input Features: tracksBufferUnion
 - ii. Output Feature: DXX_SITE_BATH_surveyDate_shorePolygon.
 - iii. Dissolve_Fields: Id

13. Edit the polygon so it is one continuous polygon with no gaps.

- a. To edit: Right click on the layer > Edit Features > Start editing
- b. Make sure the Create Features window is open (see editing toolbar) and the correct layer is selected
- c. Right click in side of the layer you wish to edit > Edit vertices
- d. To delete vertices:
 - i. Click the arrow with the negative sign in the Edit vertices toolbar
 - ii. Highlight or click the area you wish to delete from
- e. To add vertices:
 - i. Click the arrow with the positive sign in the Edit vertices toolbar
 - ii. Click the area you wish to add a vertices too
- f. To move vertices:
 - i. Click the arrow with the in the Edit vertices toolbar
 - ii. Click vertices you want to move and move it

14. If necessary, smooth edges and adjust the polygon to match the real shoreline as seen in aerial imagery. This should only be down to edit large areas (the other side of an island, a large area that the boat could not go over) and should not be used to “fine tune” point by point.

- a. Go to the Editor Toolbar>Save Edits and then Edit >Stop Editing to save your edits



Figure 8. Image demonstrating smoothing large areas to match the shoreline. In the before image (left) the blue shoreline polygon only covered one side of the island and had a large space along the right bank due to the track data (grey points) locations. The after image (right) now has the shoreline boundary following the imagery in both locations.

15. If a river- edit the ends to include all the tracks and have a “straight” edge. See figure below.

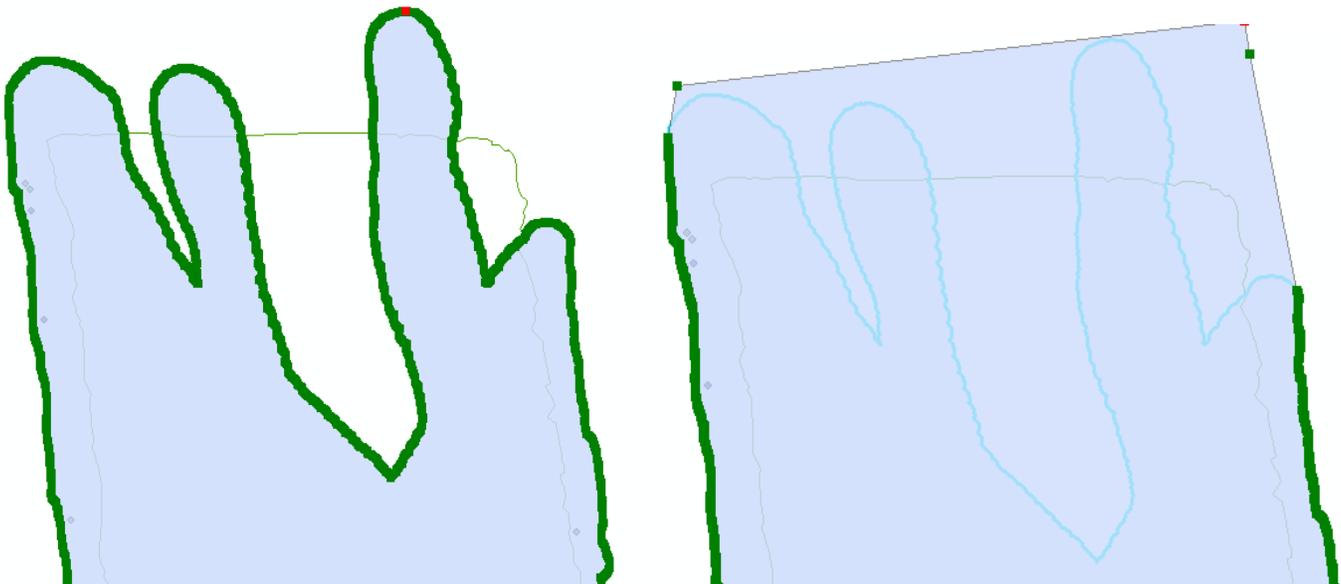


Figure 9. Image illustrating how to edit the upstream and downstream ends of a river site.

16. Edit the attribute table so there are two columns:

- a. “Name”: text field, full site name
- b. “Area” double field, right click and use “Calculate Geometry” to calculate the area in meters squared.



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17. Create the shoreline line file:

- a. Toolbox> Data Management> Features > Feature to Line
- b. “DXX_SITE_BATH_surveyDate_shoreline”
- c. Remove the “Area” field and add a “Length” double field
- d. Use calculate geometry to add the length in meters
- e. Remove any extra fields that were created during processing

18. Create a points file:

- a. Toolbox> Data Management> Features > Feature Vertices to Point
- b. Output > shorePoints
- c. Point Type > All

For all processing:

19. If a river site, remove the “short end” points so only points along the actual shore (“long ends”) remain.

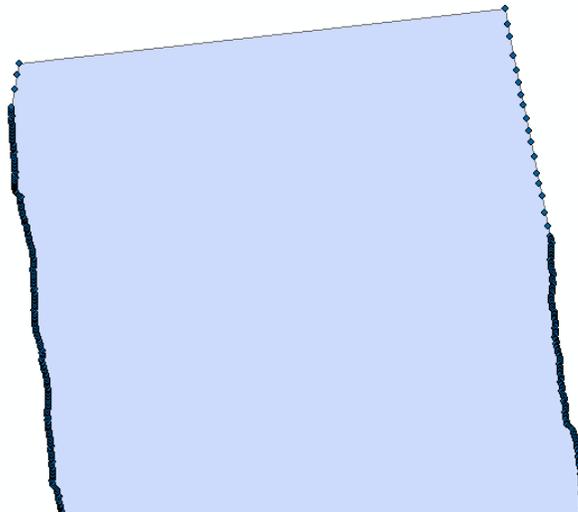


Figure 10. Removing all points not along the shore bank so points within the river are not assigned an elevation of zero.

20. Merge all the point files together.

- a. ArcToolbox > Data Management Tools > General > Merge
 - i. Selection Expression:



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1. Input Datasets: tracks, shorePoints, and if created, the output from “Generate Points Along Lines”
 2. Output data: tracksShorePointsMerge
 3. Field Map, remove all fields except: “Longitude”, “Latitude”, and “BottomElev”
 - a. Environments...
 - i. Outpoint Coordinates to match site specific UTM coordinate system
21. Make sure the elevation for all the shoreline points is “0”.
- a. Open “trackShorePointsMerge” attribute table and make sure all rows without lat/long values (the shorepoints) have a bottomelev of “0”.
22. Interpolate the data using Bayesian Kriging.
- a. ArcToolbox > Geostatistical Analyst Tools > Interpolation > Empirical Bayesian Kriging
 - i. Selection Expression:
 1. Input features: tracksShorePointsMerge
 2. Z value field: BottomElev
 3. Output geostatistical layer: optional
 4. Output raster: “SiteID_EBK.tif”
 5. Output cell: 1
 6. Data transformation type: EMPIRICAL
 7. Semivariogram model type: K_Bessel
 - a. Environments...
 - i. Raster Analysis
 1. Cell Size: Maximum of Inputs
 2. Mask: Lake Shore Polygon
 - ii. Output Coordinates
 1. Output Coordinate System
 - a. As Specified Below: WGS 9184 UTM Zone xN > OK>OK



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i. Selection Expression:

1. Input raster: SiteID_EBK.tif
2. Output polyline features: contour
3. Contour interval: dependent on lake depth
 - a. 0.5m contour for up to 5m depth
 - b. 1m contour for up to 10m depth
 - c. 2m contour for greater than 10m depth
4. Base contour: 0
5. Z factor: 1

- b. Note- the final shapefile attribute name is “Contour” not “CONTOUR”. Manually edit if necessary.

24. Define the surface volume.

- a. ArcToolbox > 3D Analyst Tools > Functional Surface > Surface Volume

i. Selection Expression:

1. Input Surface: SiteID_EBK.tif
2. Output Text File: volume.txt
3. Reference Plane: ABOVE if values are positive; BELOW if values are negative. For lake bathymetry, select BELOW
4. Plane Height: 0
5. Z Factor: 1

- ii. Repeat step with total number of isobaths displayed and merge all surface volumes into one file.

1. Change the Plane Height for each iteration by the number of graduations used for the contour lines identified in step 10.3 (0, -1, -2, -3 or 0, -2, -4, -6, etc).

25. Update the symbology for map visualization

- a. SiteID_EBK

i. Right click raster in Layers Table of Contents > Properties > Symbology tab

1. Show > Classified

- a. Classification Method = Defined Interval (identified in step 10.3)
> OK



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b. Color Ramp

i. Right click to uncheck Graphic View

1. Select Prediction > OK

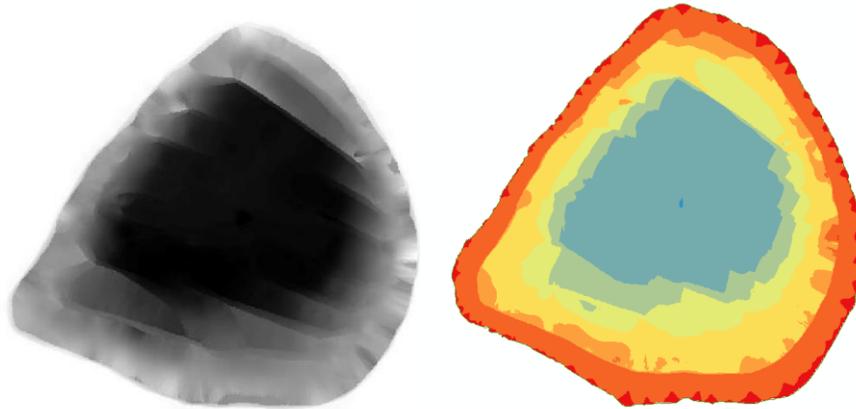


Figure 11. Bathymetry map before and after changing the symbology.

C.3 Plant Coverage

The plant coverage shapefile output from Visual Aquatic contains a percent cover value for each cell. The file is often large and takes a while to load. The plant coverage values are then assigned to a density bin and the shapefile is dissolved based on the bin values to create a more manageable layer.

1. In ArcMap, add the plant coverage shapefile created in Visual Aquatic.
2. Open the attribute table and create a new text column called “Bin”.
3. Right click on the new column and open the “Field Calculator”.
 - a. Make sure “VB Script” is selected in the Parser.
 - b. Click “Show Codeblock” and paste the script below in the box:

```
Dim density
If [Z] < 10 Then
Bin = "0-10% "
elseif [Z] < 25 Then
Bin = "10-25% "
elseif [Z] < 75 Then
Bin = "25-75%"
else
Bin = "> 75% "
end if
```

- c. In the second box: Bin = Bin



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d. Press “OK”

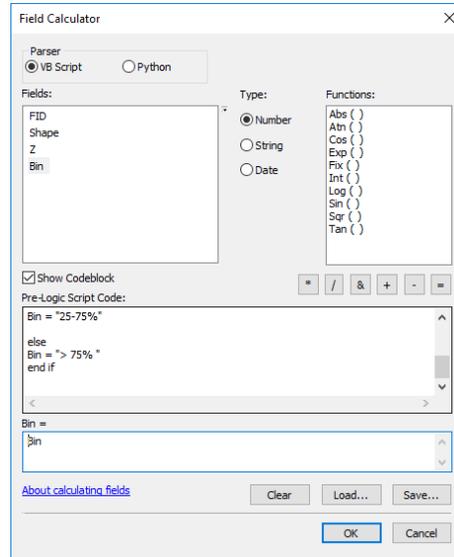


Figure 12. Field calculator codeblock to assign plant coverage values to density bins.

4. Dissolve the plant coverage shapefile by “Bin”.
 - a. ArcToolbox>Data Management Tools>Generalization>Dissolve
 - i. Dissolve_Field = “Bin”
 - ii. “Create multipart features” should be checked
 - iii. New shapefile name is “DXX_SITE_PLANT_SurveyDate”
 - iv. Make sure the only fields are “Bin” and create an “Area_m2” field.
 - v. Recalculate the polygon area using the “Calculate Geometry” rule.
5. If necessary use ArcToolbox>Analysis>Overlay>Erase to remove plant coverage from areas below the maximum plant depth.
 - a. When gridding the sonar transect data to create a continuous estimate of cover often some plant cover shows up below the max depth values.
6. If necessary, clip the final shapefile to the shorepolygon. Often the gridding step extends the layer paste the shoreline.
7. Open the .dbf in excel and save as .csv with the name “DXX_SITE_PLANT_SurveyDate_area.csv”



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C.4 Bottom Type

In the bottom type shapefile output from Visual Aquatic each cell is assigned a bottom type value (1-3 for a 3 cluster output, 1-4 for a 4 cluster output, etc). Repeat the steps below for each bottom type shapefile exported from Visual Aquatics.

1. In ArcMap, add the bottom type shapefile created in Visual Aquatic.
2. Dissolve the shapefile by “Z”
 - a. ArcToolbox>Data Management Tools>Generalization>Dissolve
 - b. Dissolve_Field = “Z”
 - c. The output file name should contain the number of clusters in the shapefile
 - d. “Create multipart features” should be checked

C.5 Random Ground Truth Points and Marked Events

Transform the random ground truth points (from the fulcrum data) and marked events (from the .rptx data) .csvs to shapefiles. Repeat the steps below for each file type.

1. Load the csv file in ArcMap.
 - a. File> Add Data
2. Display the xyz locations.
 - a. File > Add Data > Add XY Data
 - i. X Field: Longitude
 - ii. Y Field: Latitude
 - iii. Z Field: ElevationBottom
 - iv. Coordinate System of Input Coordinates > Edit > XY Coordinate System Tab > Geographic Coordinate Systems > World > WGS 1984 > OK > OK > OK
3. Export the .csv Events file to a shapefile.
 - a. Right click the Events layer and use Data > Export Data
 - i. Export: All features
 - ii. Use the same coordinate system as: shoreline polygon (UTM zone XXN, WGS 84)
 - iii. Output feature class: either “markedEvents” or “randomGroundTruthPoints”
 - iv. Save as type: Shapefile



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C.6 Creating the Habitat Map and Targeted Ground Truth Points

Once all the layers have been created multiple maps are created and compared to one another to determine what number of bottom types best fit the site.

1. Open ArcMap
2. Add the following shapefiles created in the steps above and change the symbology to best suit each file type:
 - a. Contour lines
 - b. Plant coverage
 - c. Bottom type from each cluster analysis
 - d. markedEvents
 - e. randomGroundTruthPoints
 - f. Any additional shapefiles created in the GPS Pathfinder Office export
 - i. For example, some sites will have GPS data for large woody debris or emergent vegetation in areas that were too shallow to drive the boat over.
3. Click the various bottom type layers on and off ask the following questions:
 - Which bottom type output matches up best with the random ground truth data?
 - Does the bottom type polygons make sense with the contours of the lake or river?
 - For example- at river sites there are often clay shelves along the banks that then drop off in the middle, deeper channels.
 - Does the bottom type polygons make sense with the plant coverage areas?
 - Does it make sense to combine bottom types based on ground truth data?

Some habitat maps are easy to determine. The ground truth points match up perfectly with one of the bottom type exports. Other times there are disagreements between the datasets and it is not as easy to determine which bottom type export to use.

Up to ten targeted ground truth points are created to collect field information about the benthic substrate and presence of aquatic vegetation to assist in classifying the habitat layers for the final maps. Field crews visit the targeted ground truth points within one month of the original survey to minimize seasonal changes to the benthic features.

To create the targeted ground truth points:

1. Choose the “Marker” symbol from the ArcMap Drawing Toolbar.
2. Place the marker at the location for the first targeted ground truth point.
3. Repeat for the remaining points.



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4. Select all and choose “Convert Graphics to Features” from the Drawing Toolbar and save as “DXX_Site_surveyYear_TGT”.
5. Open the attribute table and add a “pointID” text column, a “easting” double column, and a “northing” double column.
6. Edit the attribute table to label the points 1-10 in the “pointID” column.
7. Right click on each coordinate column to use “Calculate Geometry” to fill in the location information.
8. In GPS Pathfinder Office “Import” the shapefile to an .imp for field staff to use in the Trimble receiver.

After the targeted ground truth points have been checked in the field add the targeted ground truth point field information to the maps created above to determine the final habitat layers.



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SOP D Creating the Final L4 Outputs

Use **Table 1** to verify all the L4 outputs are created and named correctly. Each file is named “DXX_Site”, “BATH” or “HABITAT”, “SurveyDate”, file type.

1. Check the “DXX_SITE_BATH_surveyDate_tracks.csv” to see if the bottom type exported in 5.1.7 matches the number of bottom types that was determined to be the best fit.
 - a. If necessary re-export the tracks file from Visual Aquatic with the correct number of bottom types.
 - i. Note: this may require a re-analysis of bottom types in Visual Aquatic.
2. Save the VA dataset in the final L4 output folder in Visual Aquatic by File>Save Dataset as and browsing to the final output folder.
 - a. Be sure to remove all shapefile and .csv outputs in the folder so just the BioSonics analysis files remain, usually a “cache” folder and .vhx files.
3. Edit the bottom type shapefile that was selected as the best fit.
 - a. Make sure all the habitat polygons are dissolved so there is one row per habitat type.
 - b. Open the attribute table and create a text “Habitat” field and a double “Area_m2” field.
 - c. Fill in the “Habitat” field with the site specific values.
 - d. Calculate the area:
 - i. Right click on “Area_m2” attribute field > Calculate Geometry
 1. Property: Area
 2. Coordinate System: Use PCS: WGS 1984 UTM Zone xN
 3. Units: Square Meters [sq m]
 4. OK
 - b. Export or rename the files as “DXX_SITE_HABITAT_YYYYMMDD”.
 - c. Open the .dbf in excel and save as .csv with the name “DXX_SITE_HABITAT_YYYYMMDD_area.csv”
2. Create the final pdf maps and kml exports.
 - a. Note that the kml conversion cannot support some of the more intricate symbology patterns used in the pdf maps. Switch the symbology to a solid color before exporting.



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7 UNCERTAINTY

Spatial datasets are not a seamless representation of real-world phenomena. Interpretation of the sonar images is inherently subjective and it is difficult to quantify uncertainty that may result. Level 0 data is also packaged and served to users so that they can potentially analyze the input data used to create bathymetry and habitat maps to better understand the uncertainty associated with the maps.

7.1 Sonar Unit

A Biosonics MX, single beam, down looking echo sounder and GPS are used to collect backscatter (signal strength) data that are used to map NEON aquatic lakes and non-wadeable (river) reaches during bathymetric and morphology surveys.

7.2 Trimble GPS

A Trimble GeoXH 6000 or 7000 series GPS unit is used to collect GPS locations for the shoreline boundary, in-water features, and during ground truthing activities, throughout the bathymetric and morphology survey. Differential correction is applied during post-processing to improve GPS accuracy and reduce atmospheric errors by comparing the time signature at a fixed base station (typically CORS [Continuously Operating Reference Station]) near the rover file collected from the Trimble unit. The resulting file defines a horizontal and vertical accuracy using the root mean square error based on a 68% confidence level. NEON has aimed to utilize post-processed GPS positions that are within a horizontal and vertical precision of 10cm. Due to dense canopy at some sites and/or distance from base stations, not all GPS points surveyed fall within the desired range.



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8 REFERENCES

GPS Pathfinder Office Software Getting Started Guide. Version 4.00, Revision A (2007). Trimble Navigation Limited. Westminster, CO

Visual Aquatics User Guide. V1.0. BioSonics Inc. Seattle, WA.



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APPENDIX A EQUIPMENT

The following software equipment is needed to implement the procedures in this document. Equipment lists are organized by task. They do not include standard field and laboratory supplies such as charging stations, first aid kits, drying ovens, ultra-low refrigerators, etc.

Table 3. Equipment list – Post processing the BioSonics Echosounder data.

Supplier/ Item No.	Exact Brand	Description	Purpose	Quan- tity
BioSonics Visual Aquatic	Y	BioSonics Software	Post processing and data visualization software for BioSonics Echosounder systems	1
BioSonics Visual Acquisition	Y	BioSonics Software	Real time data acquisition, storage, and playback software for BioSonics Echosounder systems	1
GPS Pathinder Office	Y	Trimble Software	Importing and exporting data to GPS Receiver and post processing the collected data	1
ArcMap or ArcPro	Y	ESRI Software	Spatial data analysis and visualization software	1